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Research paper

Assessment of the Structure Failure of the Palm Oil Mill Effluent (POME) Digestion Tank Constructed on Peat Soil

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Abstract

The structure for extraction processes of palm oil were constructed on peat soil. Piles were commonly adopted for the foundation of such structure to transfer the imposed load to the hard layer of the soil. This study aims to investigate the probable cause of two POME digestion tanks failure at one of extraction processes of palm oil. One of the two tanks collapsed during filled up the tank with the POME and another one shows the symptom of structural failure. Based on visual inspection and analytical study, it is most likely that the failure mechanism of the POME digestion tanks is due to the deviation of the piles that induced moment onto the piles, which exceeded the structural allowable moment of the piles. There is also a possibility that the collapsed tank has been loaded to the point where piles were carrying an axial load that exceeded the said pile bearing capacity.

Keywords: *Bearing capacity, moment, peat soil, reinforced concrete pile, structure failure.*

1. Introduction

Palm oil is a type of vegetable oil that is extracted from the palm fruit which has successfully been grown on peatlands, especially in Southeast Asia countries. The extraction and sterilization processes of palm oil generated different kinds of waste water generally known as Palm Oil Mill Effluent (POME). Majority of the palm oil mills have adopted the ponding system for POME treatment while for a limited land area is available for ponding system the digesting tank is commonly adopted [1, 2].

There are several types of digestion tanks are being used in the process of the POME e.g., steel circular elevated tank, reinforced concrete elevated tank, on-ground concrete tanks, etc. Some of the POME digestion tanks were constructed on a coastal area with entire area to be overlaid with peat soil. This type of soil has a low bearing capacity and reached hard layer at 45 m to 48 m depth as indicated in soil investigation report and pile foundation was considered as the foundation of the tanks.

This paper highlighted the findings on the cause of the failure of the tank at one of the extractions and purification of palm oil facilities. Two failure POME digestion tanks structure were studied to investigate the probable cause the failure mechanism on its structure. The comprehensive investigation aims to study extent of damage to the existing POME digestion tanks and establish the probable causes of the collapsed/damaged of the tanks.

2. the POME Digestion Tanks Structure

In this case, the POME digestion tanks are circular steel tanks with 29 m diameter and 9 m in height. The tanks are resting on partly pre-cast concrete slabs of 2.75 m x 2.4 m, which are freely supported by pre-cast concrete beams of 5.5 m long on x-direction. The beams, in turn, are designed to be directly supported by piles via pile caps which are arranged in the interval of 2.75 m x 2.4 m. Meanwhile, no beam was provided along the 2.4 m span and neither beam is provided at ground level to tie the free-standing column piles. The beams should be introduced on both directions as the structure may experience lateral or horizontal loads, whether it is from wind loads on the tanks or hydrostatic loading of the POME [3].

Meanwhile, the size of pile caps on top of all piles as 750 mm x 750 mm x 750 mm. Rao (2010) stated that pile caps should be large enough to have a minimum edge distance of 100–150mm of concrete beyond the outside face of the exterior piles. In difficult driving conditions where the actual locations of piles may deviate considerably from the required, the edge distance should be increased to provide for such field variations. The layout of the tank and piles are shown in Figure 1.

The piles are extended to average 1.956 m above ground level and act as a free-standing column. At an alternate interval of 5.5 m, the beams are connected to the piles via reinforcement bars that are extended from the pile caps into the beams and second stage concrete is cast to hold together the beams and piles via pile caps. In between these piles, the beams were designed to simply rest on the pile caps without any rigid connect to the beams. Meanwhile, the piles are made of reinforced concrete having properties as shown in Table 1.

Table 1: Properties of RC Piles as Foundation

Items	Properties
Size of piles	250 mm x 250 mm
Concrete strength, fcu	45 kN/m^2
Reinforcement bar strength, fy	460 kN/m^2
Cover to reinforcement	40 mm
Bar size	16 mm
Bar no.	4

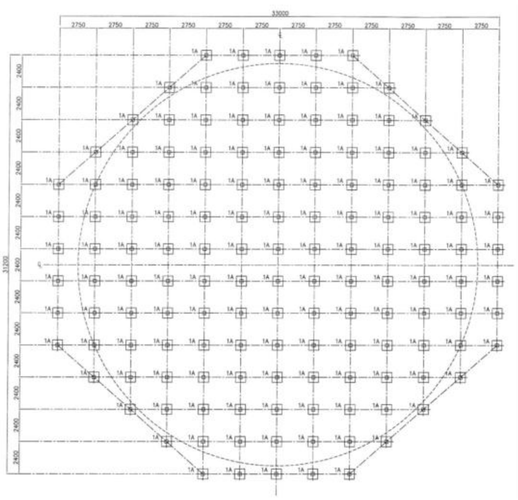

Fig. 1: Layout of piles of the digestion POME tank

There are 142 piles were used as the foundation and also as the column for the tank which was driven to the depth between 45 m to 48 m in average. Generally, the piles cannot be driven absolutely vertical and true to position. In other words, generally, the driven piles on peat soil most probably will be deviated and inclined from its intended position. Even in ideal conditions, the centre of a pile head must be allowed to deviate a certain amount from the required location [4]. In addition, the stress mechanism of inclined piles is very complicated with influences resulting from the vertical load, horizontal load or inclined load simultaneously [5]. Furthermore, based on the pile parameters as in Table 1, the relationship of axial load and moment capacity of the pile is graphically shown in Figure 2.

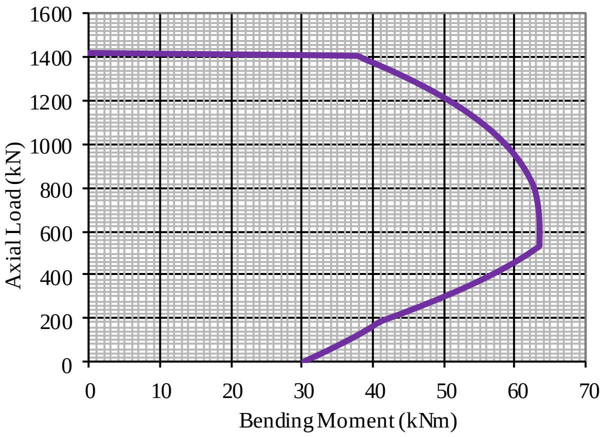

Fig. 2: The relationship of axial load and moment capacity of the pile

3. Methodology

In the course of carrying out the inspection of the collapse tanks and assessment of the remaining tanks, the following documents were provided and reviewed: (1) tender drawings; (2) soil investigation; (3) high strain pile bearing testing; (4) pile catalog and (5) piling records. This exercise provides a better understanding of the site condition and construction methodology adopted.

This study focused on the two highest tank which was 1.956 m above ground level. One of them collapsed during filled up the tank with POME up to 90% of its capacity which further called as Tank No. 1 and another one which called Tank No. 2 also show the symptom of failure even at 60% of loading. The following methodology was adopted in assessing the collapsed tank and the remaining structure: (1) document review; (2) discussion with site staff; (3) defect mapping of the structures; (4) geotechnical verification; (5) survey of the piles to establish the as-built position of the said piles and (6) carry out the structure analysis.

In the structural analysis, various loading stages on each pile which are 100%, 66.67%, 50%, 20% and 0% (only dead load – load on tank empty + structure weight) were calculated and the resulted imposed moment on each pile were analyzed. The 66.67 % loading was analyzed to check the minimum depth of 5 m for micro to service as stated in [2].

4. Finding and Discussion

Defect mapping was carried out on the structures to establish the type, shape and extent of defects experienced by the structures. The information on the type, shape and extent of the defects will enable to establish probable type and seriousness of the failures/defects being experienced by the structures. The mapping revealed that almost all piles deviated from their intended position, almost all piles inclined, the existence of gap between beams and pile caps and many piles were found to have crack close to pile cap. Mohammad et. al [6] stated that the most probable cause of the pile deviation was due to the displacement of soft ground. Furthermore, the deviation was also expected to be caused by negligent in carry out the setting out survey for the pile position.

Rao [4] categorized the deviated piles as defective piles where should be required further engineering analysis to ensure the stability of the POME tanks structure. Furthermore, Tang et. al [5] stated that the inclination also contributes to the failure mechanism whether flexure failure, shear failure or combination of the failures. In addition, the inclination of the piles also reduced the bearing capacity of the piles, especially for the high degree of inclination.

Furthermore, the piles were designed to directly support the beams and in turn support the RC platform where the POME tanks are resting. However, at the site most of these piles have deviated/offset from their intended position as shown in Figure 3. To transfer the load from the beams to the deviated piles, pile caps were constructed that extend from the piles up to the intended pile positions. In doing so the pile caps also act as a cantilever beam. This arrangement of pile caps has induced moment on to the piles. Generally, in the design, allowance should be made to cater bending stresses due to eccentric or lateral loading and to eccentricity caused by deviations in the straightness and inclination of a pile [7].

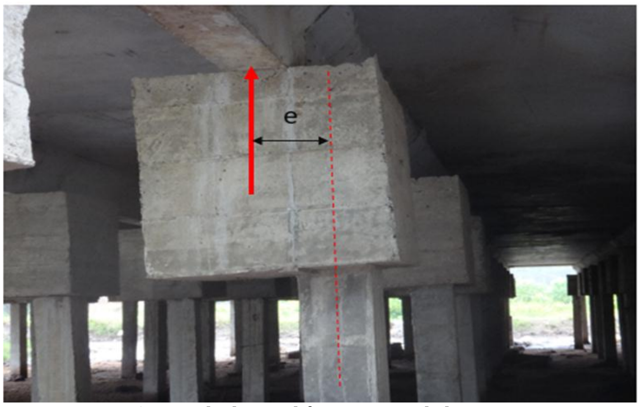

Fig. 3: Pile deviated from its intended position

In certain locations, the beams are not resting properly on the pile cap creating a gap as shown in Figure 4 and thus, the load at these piles are being transferred to the neighbouring piles along the 2.75 m span beams.

Fig. 4: Gap between pile cap and pre-cast beam

To understand the extent of the deviation of these piles, all the piles of the Tank No. 2 was surveyed at ground level and just beneath the pile cap level to establish their position. The range and percentage of piles deviated at pile cap level are 10 to 680 mm and 100 %, respectively. In addition to the above and based on survey data the inclination of each pile was also established and the type of inclination is shown in Figure 5. The range of the inclination of the piles are between 0 to 21.4 degree.

Fig. 5: Typical of existing inclination of pile

The further analysis was done with various loading on each pile for Tank No. 2 which are 100 % loading, 66.67 % loading, 50 % loading, 20 % loading and 0% loading (only dead load – load on tank empty + structure weight) were calculated and the resulted imposed moment on each pile were analysed. The piles were then checked for their allowable moment at the loading based on the graph axial load vs moment capacity as in Figure 2 above.
To establish the failure/collapse mechanism, the induced moment and induced axial on the piles due to the different loading of the POME digestion Tank No. 2 were checked against the allowable moment capacity and bearing capacity of the individual pile at the existing state. Harries [8] stated that moment capacity at the pile-to-pile cap interface is determined from the moment capacity of the pile. The result of this analysis is presented in Table 2. The typical plotting of induced axial load and moment on each pile on the diagram of axial-bending moment capacity of the piles at 100% loading is presented in Figure 6.

Table 2: The failure based on the capacity and bearing capacity of the piles

Loading (%)	Failed Due to Induced Moment Exceeded Allowable Bending Moment	Failed Due to Induced Axial Load Exceeded Allowable Bearing Capacity
100	17 piles	142 piles (all)
66.67	14 piles	0
50	10 piles	0
20	7 piles	0
0	1 piles	0

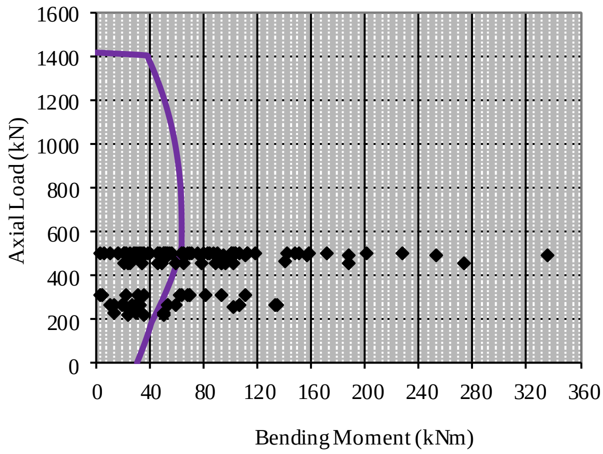

Fig. 6: Plotting of induced axial load and moment on each pile on diagram of axial-bending moment capacity of the piles Tank No. 2 at 100% loading.

Based on the above, it seems that at 100 % loading the piles of Tank No. 1 and Tank No. 2, would most likely fail due to induced moments that exceeded allowable moment capacity of the piles and induced axial loads exceeded bearing capacity of the piles.
However, at 66.67 % loading and lesser, the piles of Tank No. 2 show their piles fail due to induced moment as shown in Table 2. This would be inline with deductions made by Zheng & Li [9]. They stated that the deviation of the pile would produce large bending moment onto the pile which can cause pile failure. In addition, Phanikanth [10] stated that for the long pile, the failure is associated when the moment at one or more points exceeds the moment of resistance and the failure takes place by formation of one or two plastic hinges along the pile length.
The crack found on certain piles just beneath their pile cap as shown in Figure 7 affirmed the failure due to the moment.
The check was also done on perfect condition whereby no deviation of piles, no lateral load and only axial load working on the piles. In that respect, the only issue is the bearing capacity of the piles whereby the maximum induced axial load on the pile at 100 % loading is 503.19 kN which exceed the allowable bearing capacity of the pile which is 367.1 kN per pile.

Fig. 7: Crack underneath of pile

5. Conclusion

Based on the findings from the above works, it is most likely that the failure mechanism of Tank No. 1 is due to the deviation of the piles that induced moment onto the piles, which exceeded the structural allowable moment of the piles. There is also possibility that Tank No. 1 has been loaded to the point where piles were carrying an axial load that exceeded the said pile bearing capacity.

Based on the above, it is concluded that the probable cause of failure of Tank No. 1 and failure of the structure of Tank No. 2 is most likely due to the deviation of piles that could have induced a moment on to the piles that exceeded their structural capacity. In addition, there was also a possibility that the inadequate bearing capacity of the piles could have also contributed to the failure of the tanks. It was concluded that the Tank No. 2 could not be brought back to full load of 100 % even after rectification works.

Further, studies can be extended to the improvement method on the elevated platform constructed on the peat soil with precast pile as its foundation.

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